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Alkalinity-Driven Metal Attenuation in Acid Mine Drainage System of the Iberian Pyrite Belt: Process-Based Insights for Sustainable Remediation

JOANA FERREIRA DA FONSECA ARAÚJO JR.[1], TERESA VALENTE SR.[2], RITA FONSECA[1] AND ROBERTO DA SILVA[1]

[1]AmbiTerra Laboratory, Institute of Earth Sciences (IES), University of Évora
[2]University of Minho, Institute of Earth Sciences

The Iberian Pyrite Belt (IPB), one of the world's largest sulfide metallogenic provinces, hosts numerous mine sites where acid mine drainage (AMD) remains a persistent environmental legacy. Pyrite oxidation generates sufuric acid, mobilizing iron, sulfate, and metal(loid)s such as Al and As, leading to extreme acidity and downstream contamination (Valente et al., 2013; Jacobs & Testa, 2014). Passive treatment systems aim to neutralize acidity and attenuate metals; however, their effectiveness depends on improved understanding of geochemical metal partitioning under field-relevant conditions (Jeen & Mattson, 2016).

This study investigates alkalinity-driven transformations in AMD from an IPB mine using pond-scale experiments amended with alkaline kraft-process by-products at a 1:50 ratio. These residues, rich in lime and recalcitrant organic matter, are typically disposed of in landfills. During the experiment, pH increased from 1.64 to 6.23 within 10 days, resulting in a sharp decline in dissolved Fe concentrations (2831 to 0.19 mg/L) and substantial attenuation of associated metals (Al, As, Cd, Cu, Zn). Solid residues were extracted with ammonium acetate before and after the experiment to evaluate changes in exchangeable and weakly bound metal fractions. In addition, mineralogical analyses were conducted on the kraft by-product before and after interaction with AMD.

Results indicate that alkalinity enhancement promoted rapid redistribution of metals from dissolved to solid-associated pools, reflected by marked decreases in exchangeable Fe and selected trace elements. Attenuation patterns suggest that pH-driven hydrolysis and surface complexation dominate early-stage stabilization, preceding longer-term mineralogical maturation. This process-based understanding supports the development of low-energy and cost-effective treatment strategies for AMD-impacted mining districts.

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